

# **A Small-Scale Tiltrotor Model Operating in Descending Flight (Abstract)**

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28<sup>th</sup> European Rotorcraft Forum, Bristol, England, September 17-20, 2002

## **Introduction**

As a rotor's descent velocity in low speed flight approaches the induced wake velocity, a vortex ring is formed around the circumference of the rotor disk causing the flow to become very unsteady. This condition is known as Vortex Ring State (VRS). The aerodynamic characteristics of edgewise operating rotors in this VRS induced environment have been studied for many years. In the 1960's, two propellers were tested in vertical or near vertical descent, indicating a loss in thrust in the region of VRS (Ref. 1). References 2 and 3 reported thrust fluctuations of both single and tandem rotor configurations while operating in VRS. More recently, Ref. 4 investigated the effects of descending flight on a single rotor operating in close proximity to a physical image plane, simulating the effects of a twin rotor tiltrotor system. Mean rotor thrust reductions and thrust fluctuations were shown in VRS. Results indicated the need to acquire additional data with a two-rotor model and the need to investigate the use of a single rotor/image plane apparatus to identify the characteristics of a two-rotor flowfield. As a result a small-scale tiltrotor model with 2-bladed, untwisted, teetering rotors was tested at various states of descent and sideslip (Ref. 5). Dual-rotor, single-rotor with image plane, and isolated-rotor results were reported, suggesting the single-rotor with image plane configuration may not properly capture the aerodynamic nature of a dual-rotor vehicle. Recommendations included additional testing of a model that better represents the physical characteristics of a tiltrotor aircraft. Specific recommendations for model improvements included using three-bladed rotors, twisted blades, a tiltrotor fuselage and wings.

In October 2001, NASA Ames Research Center and the US Navy completed a wind tunnel experiment in the NASA Ames 7- by 10-Foot Wind Tunnel with the goal of further investigating the aerodynamic environment of a 3-bladed tiltrotor in descent. Objectives of this test were to obtain performance data over a range of descent and sideslip conditions and to further investigate the differences between single-rotor with image plane and dual-rotor configured models. This paper will present test results and show comparisons with results from Refs. 4 and 5.

## **Model Description**

Figure 1 shows the test installation of the tiltrotor model in the Army/NASA 7- by 10-Foot Wind Tunnel. Off-the-shelf radio-controlled (R/C) model helicopter parts were used to construct a 3-bladed dual-rotor tiltrotor model. The model could also be configured as a single-rotor with image plane and an isolated-rotor. Commercially available hobbyist radio control, transmitter, receiver, speed control, and rpm governor units were used to remotely command rotor rpm and collective pitch. Model power was provided by a 700W brushed electric motor. A 6-component internal balance was used to measure model forces and moments.

## **Test Conditions**

Dual-rotor, isolated-rotor, and single-rotor with image plane performance data were acquired over the test conditions shown in Table 1. Variable test parameters for each model configuration

included advance ratio ( $V/V_{tip}$ ), rotor collective pitch angle ( $\theta$ ), and model shaft angle-of-attack ( $\alpha$ ). Sideslip angle ( $\beta$ ), was introduced for the dual-rotor configuration only.

For each collective blade pitch, descent angle was varied from 0 to 90 deg. Advance ratios ranging from 0 to 0.15 were tested for the dual-rotor configuration. Dual-rotor configuration testing also included descent angle and collective pitch variations for sideslip angles ranging from 0 to 10 deg. Isolated-rotor and single-rotor with image plane runs were performed over a smaller range of advance ratios.

### Results

Results of this effort will address a variety of tiltrotor-specific issues, including the variation of mean thrust with descent angle, sideslip angle, and rotor collective pitch angle. Mean vehicle thrust results, shown in Fig. 2 for the 2-bladed dual-rotor model configuration, will be shown for the 3-bladed dual-rotor model. Isolated-rotor, single-rotor with image plane, and dual-rotor thrust results will be presented and compared with the results of Ref. 5 (Figs. 4 and 5).

### References

1. Yaggy, P. and Mort, K., "Wind-Tunnel Tests of Two VTOL Propellers in Descent," NASA TN D-1766, March 1963.
2. Washizu, K., Azuma, A., Koo, J., and Oka, T., "Experiments on a Model Helicopter Rotor Operating in the Vortex Ring State," *Journal of Aircraft*, Vol. 3, No. 3, May-June 1966.
3. Washizu, K., Azuma, A., Koo, J., and Oka, T., "Experimental Study on the Unsteady Aerodynamics of a Tandem Rotor Operating in the Vortex Ring State," American Helicopter Society 22<sup>nd</sup> Annual Forum, Washington, DC, May 1966.
4. Betzina, M., "Tiltrotor Descent Aerodynamics: A Small-Scale Experimental Investigation of Vortex Ring State," American Helicopter Society 57<sup>th</sup> Annual Forum, Washington, DC, May 2001.
5. Abrego, A. and Long, K., "A Wind Tunnel Investigation of a Small-Scale Tiltrotor Model in Descending Flight," American Helicopter Society Aerodynamics, Acoustics, and Test and Evaluation Technical Specialist Meeting, San Francisco, CA, January 2002.

Table 1. Test conditions

| Parameter          | Value      |
|--------------------|------------|
| $V_{tip}$ (ft/sec) | 240 to 270 |
| $V/V_{tip}$        | 0 to 0.15  |
| $\theta$ (deg)     | 0 to 30    |
| $\alpha$ (deg)     | 0 to 90    |
| $\beta$ (deg)      | 0 to 10    |

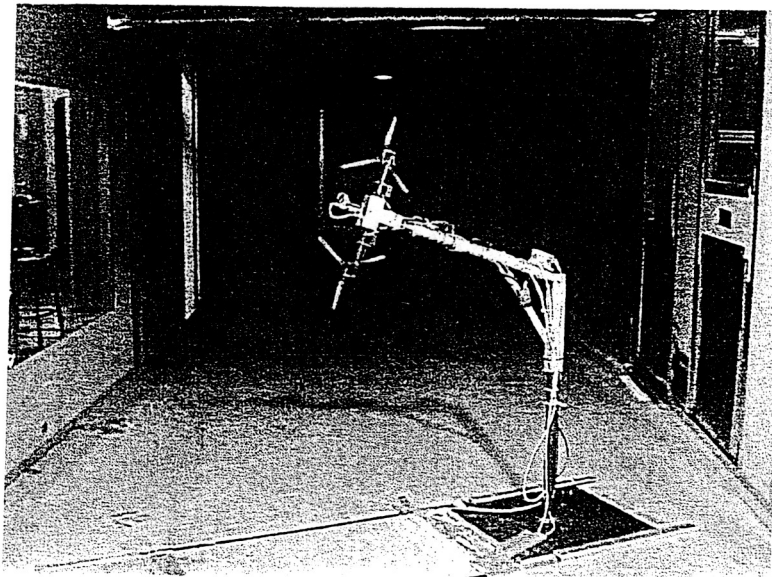
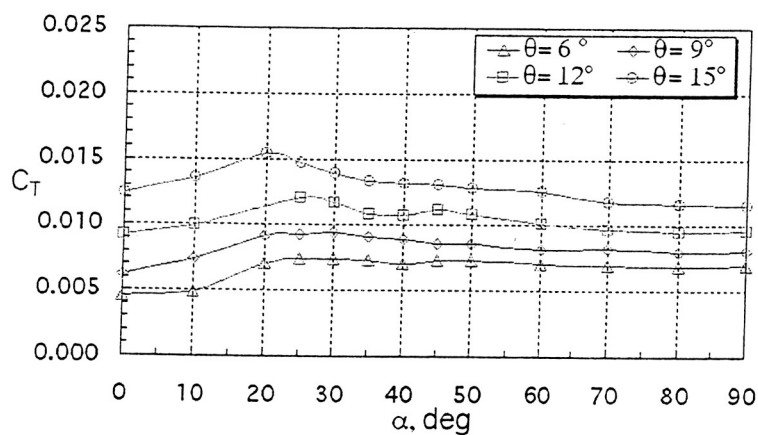
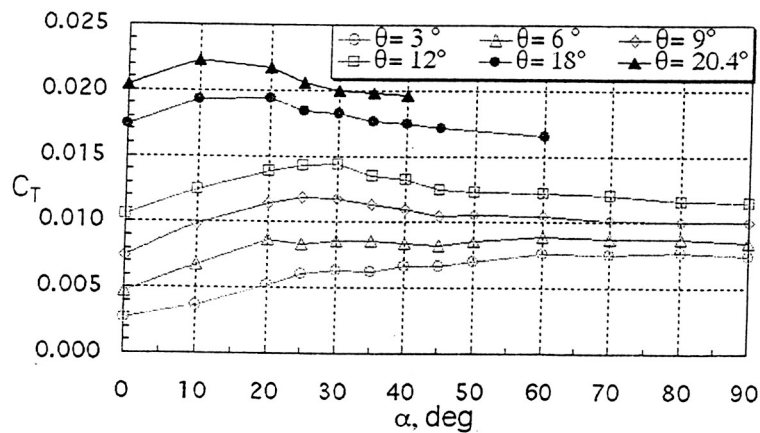


Figure 1. Tiltrotor Descent Aerodynamics test in the Army/NASA 7- by 10-Foot Wind Tunnel.



a)  $V/V_{tip} = 0.08$



b)  $V/V_{tip} = 0.10$

Fig. 2. Variation of mean vehicle thrust coefficient with descent angle, 7- by 10-Foot Wind Tunnel Test, 11.125-in diameter rotors, 2-bladed, zero twist, dual-rotor model configuration (Ref. 5).

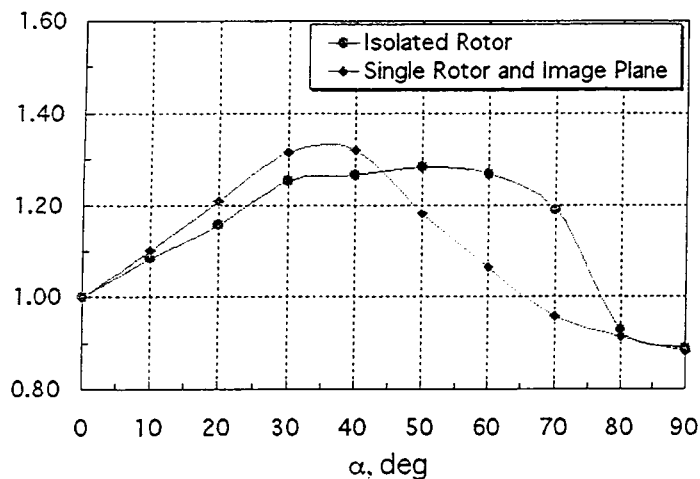


Fig. 3. Effect of image plane on mean thrust coefficient, 80- by 120-Foot Wind Tunnel Test, 4-ft, 3-bladed, highly twisted, single rotor,  $V/V_{tip} = 0.12$ ,  $\theta = 10$  deg (Ref. 4).

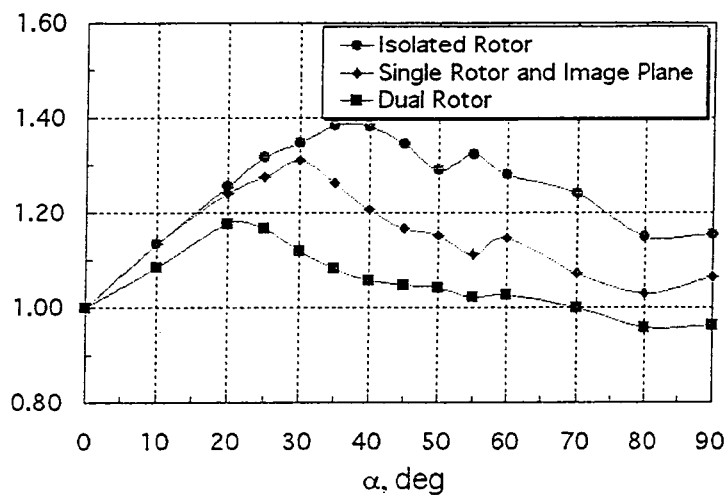


Fig. 4. Effect of image plane on mean thrust coefficient, 7- by 10-Foot Wind Tunnel Test, 11.125-in diameter, 2-bladed, zero twist rotors,  $V/V_{tip} = 0.08$ ,  $\theta = 12$  deg (Ref. 5).